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Avifauna Ethological Response to Unmanned Aircraft Systems

Elden Holldorf
eldentimothy@gmail.com

This Master's Project

Avifauna Ethological Response to
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by

Elden T. Holldorf

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Elden T. Holldorf	Date	Amalia Kokkinaki, PhD	Date

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ACRONYMS

AGL	Aboveground Level
BMP	Best Management Practices
DOD	Department of Defense
DOI	Department of the Interior
ESA	The Endangered Species Act of 1973
FAA	Federal Aviation Administration
FID	Flight Initiation Distance
FW	Fixed-Wing
MAD	Minimum Approach Distance
MBTA	Migratory Bird Treaty Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic & Atmospheric Administration
ROV	Remotely-Operated Vehicle
RP	Remote Pilot
RPA	Remotely-Piloted Aircraft
sUAS	Small/Micro Unmanned Aircraft Systems
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UAVS	Unmanned Autonomous Vehicle Systems
USFWS	United States Fish & Wildlife Service
USGS	United States Geological Survey
VTOL	Vertical Takeoff & Landing

ABSTRACT

This study investigated the ethological response of avifauna to the operation of unmanned aircraft systems (UAS). Proliferation of consumer, commercial, and military applications of UAS have provided environmental managers a new tool to use in their discipline. However, it has also promoted the need for critical examination of the effects UAS may have on existing natural resource practices, such as the management of avifauna populations. While this technology has largely been regarded as a beneficial new tool for efforts like wildlife population monitoring, it is not without potential effects to target species. This is particularly relevant to birds which share use of a common habitat feature with UAS operators – airspace. Research objectives for this project included: (1) determining how avifauna will respond to UAS operation, (2) quantify which taxonomic groups of birds have been exposed to UAS to-date, (3) identifying factors that influence the behavioral interaction, and (4) investigating the role of setback distance, or buffers, to mitigate any negative effects to birds. To accomplish this, I conducted a comprehensive literature review and metanalysis of the current body of literature reporting interactions between UAS and avifauna, distributed an original survey to US Department of the Interior Remote Pilots regarding their field observations of avifauna while flying UAS missions, and I investigated the regulatory framework for people or organizations who desire or are required to legally operate UAS within the proximate vicinity of bird species. My efforts concluded: (1) birds can respond mildly to severely, evasively or antagonistically, to the operation of UAS, (2) 87 bird species have been documented interacting with UAS as of early 2018, (3) factors of each interaction component [bird, drone, and environment] are all important variables in determining the type of reactions seen, and (4) as a general rule the implementation of a 100-meter buffer between avifauna and UAS operations should sufficiently avoid or mitigate any behavioral impacts (e.g., disturbance) to those target species. This research

may serve to inform future research and regulatory mechanisms developed around the safe operation of UAS in tandem with good conservation practices for the avifauna that now shares airspace with human beings in a new way.

KEYWORDS

buffer, setback, distance, unmanned aircraft systems, UAS, avifauna, birds, behavior, ethology, disturbance, regulations

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My cohort, professors, & advisor

SECTION 1 – INTRODUCTION

§ 1.1 – Research Focus

Over the past decade, drones, or unmanned aircraft systems (UAS), have matured from an obscure intelligence and warfare technology developed and used almost exclusively by the military, to a pervasive technology all the way through the everyday consumer market. Used colloquially, the term disruptive technology can be applied to UAS usage due to its rapid and widespread adoption across market sectors. Functionally changing the way parts of society operate, much like the internet or telephone, UAS has entered the consumer and commercial space due to the timely a combination of developments in technology, lower costs to access the technology, and new demand.

The disruptive characteristic of UAS has the potential to displace current commonplace practices or whole industries. Examples include the development of drones to deliver packages, carry cargo, and even transport humans – which correspond to potentially dramatic changes to transportation as well as technology information. The pace of UAS development and adoption has been has been particularly rapid in the last five years, with drone registration numbers overtaking the national registry of traditional aircraft in less than 2 months after the Federal Aviation Administration (FAA) instituted mandatory registration for aircraft weighing over 0.55 pounds in February of 2016 (Crutsinger et al. 2016).

One of the many disciplines that UAS has begun to transform, is environmental management. Within environmental management, UAS have been applied in the context of agriculture, ecology, emergency response, restoration monitoring, and geographic information systems. UAS are now routinely used to perform surveys and track project activities that were historically either conducted on-foot by people or by observers in manned aircraft. Their use has become increasingly common due to the cost and time efficiencies UAS afford with those other methods. For example, renting a helicopter to conduct aerial surveys can cost approximately $1000-2000 per hour, while some UAS packages and peripherals can be bought outright for those price figures (Lusk and Monday 2017).

Wildlife surveying and monitoring are examples of environmental management practices that stands to benefit from the implementation of UAS technology, particularly applied in large-scale efforts such as population census that historically required the use of manned aircraft (Fu et al. 2015, Gonzalez et al. 2016, Ivosevic et al. 2015)). Existing types of aerial surveys conducted by manned aircraft have been a valuable tool for wildlife management for several decades because they allow biologists to monitor and track species that are wide-ranging, such as birds, or species which are difficult to observe. Many types of these surveys are now being tested or refined by applying UAS methods (Jones et al. 2006, Ko and Wich 2012, Hodgson et al. 2016). This practice has seen the most widespread application in ornithological surveys for colonial species, in part due to the increased efficacy, repeatability, decreased costs, and lower human health risks by using UAS compared to manned aerial surveys. Given the large-scale global distribution of avifauna and the increasing prevalence of UAS use in the commercial sector globally, understanding and managing the interactions between UAS and avifauna is a large, contemporary challenge.

§ 1.2 – Objective & Questions

The objective of my research project was two-fold; I wanted to know how avifauna would react to UAS ethologically, and what the current regulatory framework is that either facilitates or prohibits those interactions. These topics extend from both personal and professional interests but could be of value to several interests. This work could provide natural resource managers with information to consider when designing or drafting future regulations involving permitting, provide UAS pilots a frame of reference to anticipate potential nearby avifauna reactions when mobilizing in to conduct flights, and it could also provide companies and research institutions information on the risks or assurances available when operating UAS with or without permitting or authorizations in place.

I used two questions to frame and direct the research needs to satisfy this objective; (1) How will avifauna respond ethologically to UAS operations within their immediate habitats? and (2) If the potential for negative effects exists, could distance be used as an avoidance mechanism to minimize the probability for negative interactions to occur? I hypothesized that (H1) avifauna will respond to novel UAS encounters by engaging evasion or escape behaviors; and (H2) distance is the most effective mitigation tool due to its ease of implementation and ubiquitous use as a parameter of studies in the past and in the future.

To address the primary question regarding the ethological response of avifauna, I chose several components to consider. The first (1A) was to summarize the species or taxonomic groups of birds that have been exposed to UAS operations and reported in the published literature. This was chosen as a first step because which species have been reported on and which have not, would dictate whether my findings could be applied in certain ecosystems. Additionally, I wanted to know (1B) what behaviors were observed for a given species or group of birds. This allows operators or project proponents of UAS to anticipate the types of behavior that may be elicited in the particular habitats they're working in. Finally, for the last component (1C) of the first research objective, I explored which factors would determine the interactions between UAS and avifauna. Quantifying the variables at play in this disturbance interaction could enable researchers, resource managers, and operators to designing studies or project missions to have the least impactful effect on avifauna (i.e., by choosing the appropriate equipment, site setup, etc.).

The secondary goal of this work was to propose, if possible, the use of distance as a means to minimize disturbance to avifauna from UAS operations by adhering to a buffer. This question required (2A) investigating the distance at which past UAS operators and researchers had observed bird species responding in the past, as well (2B) as a review of the pertinent regulatory framework to determine whether or not buffer distance would be feasible to implement. Although rudimentary, developing a setback distance to conduct operations could enable the development of permitting guidelines for UAS end-users. Understanding this distance, what factors contribute to it, and for which species it may be applicable, represents a first step to conduct missions without negatively impacting target or non-target avifauna. Enabling avoidance measures whenever possible to reduce wildlife impacts from operations would be advantageous to both wildlife and its conservation, as well as a means to allow UAS operators continued use of a valuable tool.

SECTION 2 – BACKGROUND

§ 2.1 – Drone Proliferation Across Sectors

Early UAS aircraft development is largely credited to the US Department of Defense, having first deployed them for military operations as far back as 1916. Civilian-class UAS are much smaller on average and have a wide array of configurations. Small or micro UAS "sUAS" are ratings typical of the types of UAS aircraft employed in wildlife surveys, and encompass aircraft with a gross in-air weight of 250 grams to 25 kilograms (including payload) (Mulero-Pazmany et al. 2017). The two main categories that UAVs fall under are either FW (fixed-wing) or VTOL (vertical takeoff and landing). FW UAVs resemble a traditional small manned plane, and multi-rotor VTOL UAVs, resembling the mechanics of a helicopter but with rotors typically configured in a four, six or eight evenly distributed rotors (Ghonge and Jawandhiya 2013, Gupta et al. 2013). See Figure 2 for representative models of each. Which type of UAV a given researcher's model falls under will dictate secondary characteristics of that aircraft, which are examined as variables of interest later in this paper. These include the engine type (e.g., gasoline or electric), how much sound the aircraft produces at idle, hover/glide, and during in-flight directional change, and the flight path, speed, and height of the aircraft (e.g., straight-line, lawn-mower pattern) (Ghonge and Jawandhiya 2013).

To understand which variables of UAS operations are of the greatest consequence in causing behavioral and physiological responses by avifauna, it is important to have an understanding anding of key avifauna and drone characteristics, and to what extent they vary in the context of wildlife research and management. "UAS" is a term that is often used synonymously with terms: "drone", "unmanned aerial vehicle" (UAV), "unmanned

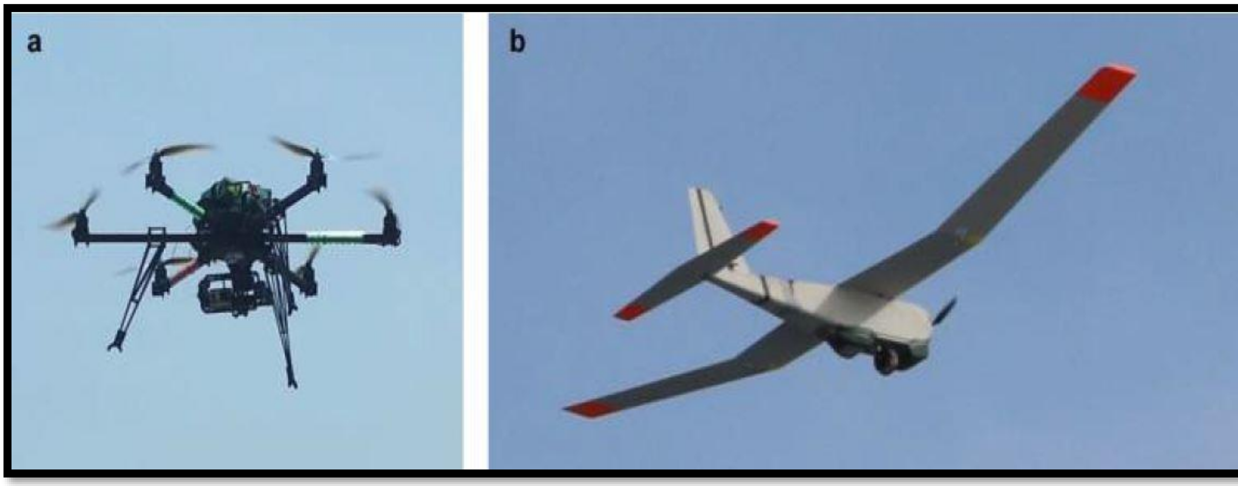

Figure 1. Primary configurations of Unmanned Aerial Vehicles in Environmental Management. Panel A shows a model classified as a multi-rotor or vertical-takeoff-and-landing (VTOL) drone. Panel B is referred to as a fixed-wing (FW) drone. Note that both types have fully electric models powered by a battery, as well as traditional fuel-powered engine models on the market.

aircraft" (UA), "remotely piloted aircraft" (RPA), and "remotely operated vehicle" (ROV) (Cox et al. 2004).

Throughout this paper, UAS is used as the blanket term to reference the activities as a whole, including the operator, and equipment on the ground or in air (e.g., transmitter, payload, radio equipment, airframe with mechanical and electrical parts, the operator or pilot, etc.). "UAV" will be used in referencing specific characteristics unique to the airframe and its parts. Not shown in Figure 1, but also technically UAVs depending on their configurations, are aircraft such as high-altitude balloons and rockets (Valavanis and Vachtsevanos 2015).

§ 2.2 – Environmental Management Applications

UAS applications within ecological research and environmental resource management have become accessible and gained popularity only within the last decade (Vas et al. 2015, Martin 2014). Use of UAS in academic and government sectors for wildlife, parallels the increase in drone use by the public and private sectors over roughly the same time span. Taken collectively, this means in addition to human implications, airspace characteristics have changed for wildlife that count airspace as part of their core habitat (Lambertucci et al. 2015). However, regulatory guidance and best managed practices to address these recent developments have lagged behind. Efforts to systematically explore the associated impacts, are still developing (Hodgson and Koh 2016).

Much of the emerging trend to use UAS in ecological research or management is attributed to monetary or temporal efficiencies and advantages gained when utilizing UAS operations compared with their respective historical survey methodologies (e.g., on-foot, via aircraft, via boat). Nonetheless, their application within wildlife research and management remains a contentious subject. While ecologists have been early adopters and proponents of the technology, UAS could also introduce a significant source of disturbance for wildlife (Christie et al. 2016). Depending on the objective, increasing UAS may be good or bad for the wellbeing of subjected wildlife.

Advantages of using UAS in this field are numerous compared to manned aerial or overwater surveys that historically used humans to visually conduct live counts of while the vehicle is in motion (Sarda-Palomera et al. 2011). Chief among the logistical benefit of UAS are: decreased time and cost associated with securing equipment and personnel to fly, lower human health and safety risk from performing dangerous job duties, increased temporal discretion in choosing weather conditions under which the study can be conducted, higher accuracy of georeferenced data, increased visibility of microhabitat features for monitoring and detection, survey repeatability, and reduced observer bias due to the fact separate researchers can execute elements of the study such as counting individuals within a colony, at a later time or can cross reference their in-field counts with more thorough analysis in the lab (Christie et al. 2016, Mulero-Pazmany et al. 2017, Sarda-Palomera et al. 2011, Martin 2014, Wilson et al. 2017).

Figure 1 provides an example of the benefits of using UAS over traditional methods, both on-foot at ground level or in manned aircraft flight, when applied to population surveys for a large colony of birds. The smaller, vertically-stacked panels show that individual seabirds are easier to quantify when they are in a still frame versus live counting while flying. Additionally, they appear less clustered and obscuring one another when photographs are collected from overhead. Note, the large panel represents a processed orthosmosaic constructed from multiple photos being stitched together to represent the whole colony

In addition to logistical survey advantages, the use of UAS may also have the effect of reducing or eliminating disturbance to the subject species. Smaller size and reduced noise, are two easily quantifiable metrics often embodied by UAS aircraft compared to their manned aircraft analogs (Christie 2016, Watts et al. 2008). For example, surveying large mammals like caribou can be done from a height where the individuals do not elicit a vigilant response to the aircraft. Because of its small size and electric motor the subject species is still able to be accurately censused without low-altitude, high-resolution efforts (Martin 2014, Smith et al. 2016). Even compared with certain on-foot survey methodologies, UAS may confer cost and time advantage to the researchers as well as the study species, wherein UAS-collected imagery may negate the need to have micro-habitat plotted such as taking GPS points for nests (Sarda-Palomera et al. 2011, Watts et al. 2010). Much of the work that assesses the advantages of using UAS are proof-of-concept, although some surveys for some species are becoming more standardized.

Figure 1. Comparison of static viewing perspectives witnessed during unmanned aircraft system operations compared to stationary on-foot observers. These panels illustrate increased ease and efficiency of conducting a population census for large bird colonies using orthoimagery mosaics. (*Brisson-Curadeau 2017*).

Disadvantages or risks associated with using UAS for wildlife research are less well-documented. The uncertainty associated with implications of UAS on wildlife has already seen significant consequences – namely multiple local and federal conservation entities banning UAS flights on their lands in an observance of the precautionary principle (Vermeulen et al. 2017). There has also been a lack of mechanisms for researchers or commercial operators to obtain permits or waivers for those activities. However, recent papers that attempt to quantify these potential impacts indicate ecologists and resource managers are aware of the increased need for study of this aspect. (McEvoy et al. 2016, Lambertucci et al. 2015, Brisson-Curadeau et al. 2017, Smith et al. 2015, Hodgson and Koh 2016, Barnas et al. 2017).

UAS operations have been applied across a wide range of taxonomic groups encompassing aquatic and terrestrial life forms from fish to elephants (Christie et al. 2016). However, researchers conducting a recent meta-analysis of UAS wildlife studies identified birds as being the more likely to react than other taxonomic groups (Mulero-Pazmany et al. 2017). This makes sense given avifauna's inherent potential conflict resulting from shared use of airspace (Vas et al. 2015). The remainder of this study will focus almost exclusively on avifauna as the focal taxon of interest – and more specifically, only those for which UAS encounters or surveys have been reported. Toward the end discussion is provided regarding the applicability of these data toward making assumptions about the bird groups not represented herein.

§ 2.3 – Avifauna Disturbance from Human Activities

The term avifauna refers to the phylogenetic group at the class-level called Aves and is inclusive of all of birds. This group is an incredibly diverse and well-distributed taxon. Birds have been a highly valuable natural resource for humans across space and time for a variety of reasons. They hold economic, agricultural, and ecological value for their ability to moderate pest populations. They also have held economic value as parts like feather for trade in the past—largely a thing of the past at least in the United States as a result of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and other landmark conservation laws). Additionally, they serve cultural (e.g., symbols of a place or societal group) and recreational (e.g., birdwatching, hunting), purposes to humans. For these reasons, as well as their crucial functions within food webs and ecosystems, understanding the impact of human activity on this important phylogenetic group is of keen interests to ecologists and environmental managers entrusted with protecting the resource.

The evolutionary history of birds is long, complex, and often shrouded in fervent debate within the discipline of paleontology and ornithology. Avifauna evolution truly dates back in time to Jurassic-period dinosaurs – as the Aves class is now widely accepted to be the closely extant representative of dinosaur lineages (Godefroit et al. 2013). Emblematic traits such as flight or pair bond breeding, are often used to make colloquial groups of birds as previously mentioned, but this practice can produce misleading conceptual groupings of bird species, given their convoluted evolutionary histories wherein traits can evolve independently on the globe or even me subsequently lost and modified for a different purpose.

Recent large-scale genetic work to consolidate some of the fervent debate over the evolutionary history of living bird species resulted in some counterintuitive, but well-supported evidence for the existence of five major groups of neoaves (Prum et al. 2015). The important thing to recognize is that when comparing which species will react similarly or different than another species, for example trying to extrapolate the behavioral response of one species that has encountered UAS operations to another seemingly closely related

Characteristics of avifauna that past studies have found to be important in anticipating behavioral or physiological response of birds have been life-history stage (i.e., during the breeding season or not) and level of aggregation (e.g., colonial or territorial) (Mulero-Pazmany et al. 2017). Although UAS and avifauna interactions are a relatively nascent phenomenon, the concepts of wildlife disturbance from human activities, and the airspace conflict between aircraft and birds, have a much longer scientific history. Conclusions drawn by past research in this subject, are helpful for anticipating future novel scenarios such as the interactions between contemporary birds and UAS operations. For example, past research has shown that negative effects from human disturbance can have significant effects on the exposed species. Among them are reduced feeding, reproductive success, fecundity, and survivorship (Livezey et al. 2016).

Past studies identifying those detrimental effects are important for anticipating what long-term effects repeated exposure to UAS might have on avifauna in the absence of proper management.

§ 2.4 – Regulatory Framework & Uncertainty

Legal operation of UAS in the United States is a complex effort. Technology often outpaces regulation, or triggers it, as legislative bodies often have to respond to new activities or equipment as the public raises concern. Commercial entities including businesses and research bodies like universities, typically express and demonstrate a desire to conduct all of their activities within the law as it keep their image reputable to the public and it affords them consistency and the ability to plan for future efforts. UAS and the widespread adaptation of their use is one such example of regulation in flux as a new technology rapidly emerges.

The legal context of UAS has been changing frequently over the last 2 years in terms of who may operate drones, for which purposes, and what documentation (e.g., drone registration, pilot certifications) is required to demonstrate compliance (Federal Aviation Administration 2017). In addition to the legal logistical considerations for operators, there are also legal implications for the interactions with wildlife. Wildlife species are generally treated as a trust resource of the government in the United States, and their management or stewardship is spelled out under various environmental laws. However, there is currently little explicit guidance from local, state, or federal government regarding the operation of UAS near or within wildlife species' habitat. The same is true for case law on this topic. Several lawsuits involving drones are currently in-progress, as of this writing, the author has not found any domestic lawsuits pertaining to wildlife disturbance in terms of UAS.

Nevertheless, the potential for UAS to disrupt normal wildlife behavior has resulted it the banning of drones on certain properties like national parks and refuges in response to public concern (Martin 2014). This has, ironically, made the study of UAS effects on wildlife somewhat precarious for researchers and commercial operators in the absence of direct legislature other than certain agencies' explicit ban based on protected property areas.

The FAA is the governing and regulatory authority for national airspace operations (a duty it shares with DoD to some extent). The FAA has in recent years made substantial progress towards incorporation UAS operations into the national airspace. Actions among these first steps toward a robust regulatory framework for operations, has been the certification of remote pilots (RP) who are qualified to operate unmanned aircraft in certain size/weight classes as well as a waiver and authorization program for flying in restriction airspace. Because regulatory authorities are just beginning to develop guidance and restrictions on UAS operations, research and management implications of operating UAS in the vicinity of birds has caused confusion among RPs and researchers (Paul 2018). To a certain extent, these concerns are shared by and apply to recreational consumers as well (e.g., racers, airplane model hobbyists) – although the focus of this present study is primarily the commercial sector in research, environmental management, and business.

In the United States government, federal authority for enforcing laws and issuing permits for activities involving wildlife, are jointly held by the US Fish and Wildlife Service (USFWS) within the Department of the Interior (DOI) and the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) within the Department of Commerce. The respective agency's jurisdictions are largely determined by whether a species spends the majority of its life in terrestrial or marine environments. While some species have been inherently problematic to assign jurisdiction over because they occupy both types of environments throughout the duration of their life (e.g., some turtle, salmon species), bird species and activities that affect them are regulated and enforced by the USFWS. This is true even for birds that primarily occupy coastal and marine habitats.

SECTION 3 – METHODS

§ 3.1 – Literature Review

To address the first objective of my project pertaining to how birds will react to UAS operations and what factors affect the response, I began by performing a literature search using online databases. I collected and reviewed ecological, environmental management, and other related disciplinary literature that had recorded behavioral responses of wildlife to UAS application broadly. All studies that discussed UAS and wildlife behavior were examined, regardless of taxonomic classification, to examine the range and types of research that had been done to-date. From there I further refined my searches to publications that addressed birds specifically.

Elsevier's Scopus was the primary database used and accessed through the University of San Francisco's Fusion library search function. Google Scholar and Google Search were also used intermittently to assist in sourcing obscure references. At the onset, I applied mixed combinations of keyword searches which linked UAS applications with ecological studies of wildlife. The following terms were used to within the searches: "drone(s)", "unmanned aircraft system(s)", "unmanned aerial system(s)", "UAS", "unmanned aircraft vehicle(s)"', "unmanned aerial vehicle(s)", "UAV", "ecology", "conservation", "biology", "ethology", "disturbance", "response", "wildlife", "monitoring", "animals", "behavior", and "survey".

These database search combinations yielded 60 sources total when using variations of a combination of one UAS term in combination with one ecology or similar discipline term. The relatively sparse body of literature on this subject and the concentration of them (>90%) being published in the last 5 years suggests the field is still developing. I reviewed the top reviews and meta-analyses to acquire a preliminary sense of how researchers had applied and measured the impact of the technology in relation to ethology.

To refine my search of research pertaining to the ethological responses of avifauna, I gathered all preexisting records of studies that contained some aspect of interactions among birds and UAS. I performed a round of searches with the keywords: “bird”, “avifauna”, “aves”, “breeding”, “nest” and “nesting”. I did not restrict the searches based on their geography or the language studies were written in, although searches were only performed in English. Due to the small number of studies available, I further mined references from the “literature cited” or “references” section of various publications, to obtain as many UAS/bird-focused research as possible to be used in this meta-analysis of the existing work. This proved to be a beneficial strategy, because once I began seeing the same studies cross-referencing one another, I could attain a fair level of confidence that I had likely collected most of the representative works on the subject. This effort produced 38 references that became the primary material from which I gathered specific data related to my variables of interest. All references were compiled and searches were completed by April 15, 2018.

The articles specifically mentioning any bird species and some aspect of UAS, where then separated into reviews, topical, and original categories. References were categorized as reviews if they mentioned or synthesized other research but did not contain new information or records by the authors themselves. References were categorized as topical if they were only discussing topically, the interactions among birds and UAS. References were categorized as original if they published new observations of the interaction between a bird species and UAS of any kind, as reported by the authors for the first time. Those original studies were considered regardless of whether or not quantifying behavior was a chief objective of the study.

I extracted various data from this collection of avifauna references and compiled the pertinent information in a spreadsheet computer program. From all of these sources, I recorded the names of the authors and the year of publication to refer to the body of work in all future steps of the review and in drafting the final project report. Both the common and scientific names of any birds mentioned were recorded. For the reviews or topical articles, I double checked that I had previously collected individual studies they were discussing and categorized it as an original – to be used subsequently to extract additional data. If those reviews contained new studies, I would search for the target publication and add it to my list of publications to review.

Articles containing original observations of interactions between birds and UAS, were further annotated to collect parameters characterizing their site setup, primary intent, which drone models were used, as well as flight characteristics. Data I recorded on the setup of the research included: year(s) performed, where the site, city, and/or country location(s) were that the study took place, along with what the goal of the research was. I classified the goal of the research in one of three groups: habitat, census, or response.

The habitat group included studies that were primarily focused on either conducting habitat monitoring or testing the feasibility of mapping applications with UAS. The census group was comprised of studies who were either monitoring populations of birds using UAS, or that were interesting in piloting the first feasibility studies of where or not UAS could be used to effectively count populations sizes. The response label was applied to studies that identified either quantitative or qualitative assessment as an objective of their research, even if it was not the primary objective, since this was the type of work of most interest to me.

In addition to the common and/or scientific name of the focal avifauna species, I collected data on the characteristics of birds from studies that I had either noticed were data collected by others from my preliminary wildlife behavior research, or that I simply had an innate sense might be importance in these interactions. From the studies I identified as original and presenting firsthand UAS findings, I created fields in the spreadsheet and populated the data of interest, including the age class of subject avifauna individuals (juvenile, adult, both), whether or not they were in solitary or gregarious/colonial assemblages at the time they were observed, as well as their reproductive status (breeding, nesting, or neither/unknown) if it was known. I also noted the behavioral response of the target wildlife (e.g., increased vigilance, flushed from nest, etc.) as reported by the researchers, as well as the method used to record and quantify behavior. In a vast majority of the studies, a human ground observer on site at the time of interaction was the primary method used to measure behavioral response, while some quantified response of colonies by a percent disturbed of the whole in a lab setting (e.g., reviewing aerial footage collected by the drone overhead).

Data about the UAS model's characteristics were also collected from the original avifauna-UAS interaction publications. These metrics were identified as potentially relevant from preliminary investigations when sourcing general wildlife/UAS interactions, as well as analogous metrics described in the wildlife disturbance literature – particularly from older papers assessing the effects of manned aircraft surveys on wildlife. Those variables of interest were the make/model of the drone used, its form of propulsion (electric or fuel-powered), and its mode of flight in terms of the design configuration (fixed-wing or vertical-takeoff-and-landing). Closely linked and somewhat dictated by the specific UAS model configuration, are parameters of the actual flights executed. The metrics for which I collected data on flights executed by researchers were the minimum and maximum height aboveground level (AGL) reported for the entire duration of the study, as well as the minimum/maximum intervening distance between the UAS and a bird(s) responding to the flight. Throughout the rest of the study I refer to this as the "initial response distance". This is to signify the conservative (i.e., most likely to avoid impact) strategy I used when determining the distance at which a bird responded. Some studies I classified as response studies, explicitly tried to provoke a strong reaction from the target species to determine at which distance a response is significant, such as flushing and potentially causing a mid-air collision, from the operators' perspective (McEvoy 2016, Vas et al. 2015). In those instances, the "initial response distance" was taken as the distance, which might be the distance at which increased vigilance is observed via high or low head scanning – as opposed to the shorter response distance wherein a bird would flush due to immediate proximity of a flying UAV.

Figure 3. Panels illustrating the range of potential avifauna ethological response categories in the field. From top to bottom: (1) evasive, flushing (Lyons 2018); (2) neutral, resting (Barnas 2017); (3) antagonistic, dive bombing (Lambertucci 2015).

In most cases, flights occurred overhead of birds on the ground that were foraging or nesting (Gardner et al. 2011). If there were deviations from this setup, I noted the bird's height AGL as well, to be able to subtract or account for the bird's height in relation to that of the UAS model to get the intervening distance. In one instance of cliff-roosting birds, the reported distance was horizontal in relation to the target species position (Brisson-Curadeau et al. 2017). If any distances were not already reported in meters I converted them.

I also noted the flight pattern the researchers chose and categorized them into either straight-line (a linear motion direct to/from target avifauna), lawn-mower (consistent sinuous direction – typically used in aerial mapping applications), or erratic (irregular, undetermined motion) flight pattern categories. This was another parameter of the flights that I elected to collect based on early articles I reviewed that identified it as potentially affecting the bird's behavior in proximity to UAS.

Towards the end of my literature review process, I searched for laws and regulations that pertain to this topic. I used the US Library of Congress online search function to sift through regulatory and statutory documents that pertained to search words similar to those described above for the scientific literature, including: "drone(s)", "unmanned aircraft system(s)", "UAS(V)", "unmanned aircraft (aerial) vehicle(s)"', "environment", "ecology", "conservation", "biology", "ethology", "disturbance", "harassment", "take", "wildlife", "behavior", "survey", "permit(ting)", "welfare", "take", and "protected". These searches returned far more results than I had anticipated, and from reading summaries was able to omit regulations that pertain to the captive and/or laboratory settings, as well as those that dealt with hunting or sale of bird species or parts. While it is not out of the realm of possibility that individuals could use UAS to hunt or trap avifauna, most likely in terms of enhancing hunting strategies through increased ease of monitoring and reconnaissance, I elected to not further investigate those laws as the focus of this work was primarily on the commercial market – where unlawful activities can hold severe consequences for those intentionally engaged in illicit activities. This inherently deters commercial operators to pursue such actions.

Once I collected the four regulations that I interpreted to be immediately applicable to the operation of UAS in avifauna habitats, I examined whether or not there existed provisions or allotments within each statue to allow any federal agency to permit that activity. NOAA's NMFS has developed and made public, some of its work regarding a permit application protocol and guidance for the operation of UAS in the agency with authority over birds in the US is. However, the USFWS has not explicitly responded to some vocal non-for-profit organizations and their vocal member (Paul 2018).

A lack of memoranda to the public from the USFWS could, however, be indicative of internal changes to the implementation of certain authorities of law, given that a new administration with a new ruling majority political party has recently assume the lead of the executive branch of the US federal government. Coincidentally, a few short months ago the DOI Solicitor's Office issued a revised interpretation of the Migratory Bird Treaty Act's (MBTA) authority to issue violations or prohibit the "incidental take" of MBTA-listed species, via their Opinion M-37041 (DOI Solicitor 2017). That document clarifies the expected appropriate interpretation of incidental take to be narrowly defined and applied to activities in which the effect to avifauna is the primary objective of the action. That is, as opposed to incidentally harming, harassing, etc. birds in the course of carrying out otherwise lawful activities. Keeping this in mind, I explored the implications of the pertinent laws I interpreted to apply to conducting UAS flights in the vicinity of birds and summarize those in Table 4 of the Results section below.

§ 3.2 – Remote Pilot Survey

In addition to a review of the publicly-available literature, a goal of mine at the onset of the project was to collect and process original data regarding the potential responses of avifauna to UAS operations. However, given time constraints and the intended scope of the University of San Francisco Master of Science in Environmental Management capstone project, it was infeasible to conduct fieldwork-based research. In lieu of executing ethological studies in the lab or field, I piloted the use of an online survey form to gather novel data on this subject from certified Remote Pilots (RPs) at the DOI. These data serve to supplement and compare the results of the literature review data collection.

DOI RPs were targeted to as a source to query data from for several reasons. Chief among them was their level of experience flying UAS missions in conjunction with their technical expertise of environmental management issues. Given these collective traits and the environments that DOI operate within, I felt the cadre had ideal traits for contributing meaningful and novel data to this research. Another appealing characteristic of the cohort at-large was my access to their network as a fellow certified DOI RP myself. Issuing the survey to this internal network produced a unique offering of data for my analysis and I suspect provided participants some level of confidence that their responses would not be misconstrued as intentional harassment.

I drafted questions contained therein with two underlying goals. The first was to extract pertinent information that would be relevant for making comparisons to data I compiled during the primary literature review effort. Provided the schedule and timeline for the project, I note that my literature review and the writing of questions addressed within the survey form, occurred concurrently. As such, there were some fields of data collected that were not utilized in the final meta-analysis linking the two methods. This was the result my investigation of secondary research question (variables influencing the resultant behavioral interactions between birds and drones) being incomplete prior to distributing the survey.

My second goal was composing survey questions that facilitated the exchange of ideas I may have not yet considered prior to contacting the cadre of pilots. The survey form program I used was Google Forms. This program includes features a survey writer may use to restrict the response formats that would be accepted for a given question. I used a combination of multiple choice, as well as freeform paragraph response, type questions to frame the survey questions. To satisfy my second objective, I attempted to write unrestricted options to respond wherever practicable (i.e., at least one option would be sufficiently open-ended that RP participants could apply their professional discretion and respond in a way that may have not been outlined by my proposed choices). An example would be an "other" option within otherwise pre-defined choices of a multiple-choice question.

Below is a verbatim of the language and questions that were contained in the Google form distributed to nearly 200 DOI RPs. The original text is italicized. I prefaced the survey by explicitly stating participation was optional, and that results would be reviewed and reported confidentially without identifying individuals when discussing the results. Preceding a question or group of questions, I describe the rationale and variable(s) of interest that the question(s) was designed to address. In total, I received 20 submissions each representing an individual DOI RP and their accounts of interactions with you

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PREFACE

TARGET: Federal remote pilots (RP) able to report observations of avifauna behavioral response to official UAS activities. Soft deadline to complete this is Friday, 16 March 2018. This form in its current iteration will be removed Friday, 30 March 2018.

INTENT: These data will complement a current analyses of published avifauna ethological response to UAS, undertaken as part of a fellow DOI RP's graduate environmental management work. The immediate objective is to develop UAS minimum approach distances (i.e., setback, buffer distance) for various types of birds, as a mechanism for minimizing disturbance. In the future, this could potentially serve as a framework for proposing guidance, BMPs, and permitting criteria.

*INSTRUCTIONS: Use this form for any one unique combination [drone + bird + behavior] of observations, including both single and repeated instances. Use a new form to describe different scenarios/responses**. If you are reporting multiple events of the same type but there is variation, simply enter the range of values or report the most conservative one. Your distance estimates in questions 4-6 are of greatest interest. Your individual responses and respective contact info will be kept confidential. Be sure to reference your agency's individual guidelines/procedures for taking surveys on official duty time and determining whether approval may be required to participate. Please contact elden_holldorf@fws.gov with questions/concerns.*

***If you have amassed many observations and consider this form prohibitively time-intensive, contact the email above to obtain a spreadsheet version.*

QUESTION 1 OF 13:

Responses to the first question indicated to me specifications of the aircraft, without requiring the participant to provide those separately (e.g., power type, fixed-wing or multirotor, etc.)

Which UAV model were you flying?

- *3DR Solo*
- *Pulse Aerospace Vapor 55*
- *BirdsEyeView FireFLY6*
- *Falcon Fixed-Wing*
- *Falcon Hover*
- *Other…*

QUESTION 2 OF 13:

The following question allowed for the participant to report the species of bird down to the taxonomic resolution they were comfortable or familiar with.

What bird species did you encounter?

- *Common name (e.g., western osprey) or scientific name (e.g., Pandion haliaetus) preferred; if unknown, use a colloquial category (e.g., raptor, seabird, passerine, etc.).*

QUESTION 3 OF 13:

Question 3 through Question 6 provided information to later determine the initial response distance for the species reported in Question 2.

What type of disturbance behavior did you observe?

** in this context defined as a change in behavior likely attributable to the UAS operation regardless of the strength of the response; does not necessarily constitute harassment*

- *increased vigilance (e.g., alerted/scanning head movements, curious posture, alarm calls)*
- *active evasion (e.g., moving away from UAS, fleeing, flying, seeking refuge)*
- *active aggression (e.g., moving toward UAV, territorial posture, lunging, diving, mobbing)*
- *Other…*

QUESTION 4 OF 13:

What was the intervening distance between the UAV & BIRD ("as the crow flies")?

** estimates expected, measurements welcome, please indicate units*

QUESTION 5 OF 13:

What was the altitude (height AGL) of the UAV?

** estimates expected, measurements welcome, please indicate units*

QUESTION 6 OF 13:

What was the altitude (height AGL) of the BIRD?

** estimates expected, measurements welcome, please indicate units*

QUESTION 7 OF 13:

Question 7 provided a good medium for the participant to report their perceived accuracy in the estimates they were providing. This gave me a way to quantify the merits and/or usefulness of the distance which was very helpful during processing.

Rate your confidence in the accuracy of the above 3 estimates.

** factors to consider might include whether you have been able to compare your estimates to instrument measurements in the past, how far away you were from the observation, whether you're recollecting these figures now or referencing those data records recorded in the field, etc.*

- *LOW | 1 | 2 | 3 | 4 | 5 | HIGH*

QUESTION 8 OF 13:

Question 8 through Question 9 provided information on the factors potentially involved in determining the initial response distance. These were related to characteristics of the UAV model and/or flight path operators used.

What was the approach ALTITUDE, relative to the bird's position? I.e., how was the UAV flying vertically?

** Please select the choice representing the most majority of approach time.*

- *mostly level*
- *ascending quickly*
- *ascending gradually*
- *descending quickly*
- *descending gradual*
- *Other…*

QUESTION 9 OF 13:

What was the approach FLIGHT PATH, relative to the bird's position?

** I.e., how was the UAV flying horizontally? Please select the choice representing the most majority of approach time.*

- *lawn-mower pattern (sinuous)*
- *directly towards bird (straight path)*
- *directly away from bird (straight path)*
- *alongside bird (parallel to the bird's dorso-ventral axis)*
- *Other…*

QUESTION 10 OF 13:

Question 10 through Question 11 provided information on the factors potentially involved in determining the initial response distance. These were related to characteristics of the bird species or colony that were observed.

What was the level of avifauna aggregation at the time of observation?

- *single individual*
- *multiple individuals, single species*
- *multiple individuals, multiple species*
- *Other…*

QUESTION 11 OF 13:

Were the behaviors observed during the breeding/nesting season for the bird species?

- *Yes*
- *No*
- *Unknown*
- *Other…*

QUESTION 12 OF 13:

Question 12 allowed me to determine if there were multiple independent repetitions or pseudo-replicates by being able to report the number of times they had witnessed a particular UAV/bird response combination.

How many instances (events) are you reporting on this form?

QUESTION 13 OF 13

Any feedback or additional detail re: your above responses is welcome below. Also, indicate if (1) you prefer NOT to be contacted if follow-up questions arise, & (2) if you are NOT a RP with DOI, please indicate your affiliation. Thank you very much for your time.

- -

Finally, I also completed a Google form as a participant and in doing such added one more unique data point to this set from my own experiences pilot UAS flights. The idea for this project in general stemmed from an encounter I had in June 2017 with a Rufous hummingbird (*Selasphorus rufus*) in Sacramento County, California. I was flying a multirotor VTOL micro-UAV when very rapidly, a hummingbird appeared and instantly started darting at the UAV model before I quickly made an emergency landing. I was surprised to encounter an unprovoked bird actively pursuing the UAV but later found that this species of hummingbird is known for being daring and aggressive (Clements et al. 2017). I have included this observation both as a nod to the inspiration for this project as well as supplementing the data set. I was not able to find any other mention of hummingbirds responding in proximity to UAS operations.

§ 3.3 – Meta-Analysis

Once all publications were annotated and relevant data were collected, in tandem with receipt of the DOI RP survey responses, I began to synthesize the data for the results of my project. The steps taken to address the first question, for which species interactions with UAS have been recorded, was the most straightforward to synthesize.

During active review, I made note of any bird species that authors mentioned. This included bird species only briefly mentioned. For example, I still made note of species that were essentially non-target species as long as the researchers recorded behavior that I could confidentially quantity as (Turecek et al. 2016, Lyons 2018). The rationale for recording the broadest possible treatment of wild bird interactions in this case, is that it provides a snapshot of the entire known species or groups that have encountered UAS. This quickly and conveniently illustrates which groups have been already studied in depth, and those for which no records have been observed whatsoever.

The 2017 edition of the Clements Checklist was used in conjunction with current eBird database conventions to create a comprehensive list of the taxonomic classifications of those birds (Clements et al. 2016). I chose these two resources due to their ubiquity among ornithologists and their exhaustive global coverage of birds – as the phylogenetic relationships of birds is frequently redefined, often complex, and sometimes counterintuitive. These classifications were populated in my master spreadsheet and subsequently ordered by their respective rank, including: Domain, Kingdom, Phylum, Class, Order, Family, Genus, and Species. All birds shared the following classifications: Domain = Eukarya, Kingdom = Animalia, Phylum = Chordata, and Class = Aves. The subsequent hierarchical taxonomy groups were distinguished for each species (Order Family, Genus, Species) and also recorded in the master project spreadsheet.

Due to substantial variation in how frequently different suites of species were assessed in the literature, birds of similar life history or habitat occupancy traits were grouped into one of seven colloquial categories for use in further analysis. These categories are shown, along with their respective Order name, Family name, and [Genus] Species count in Table 1. The categories I chose were Birds of Prey, Flightless Birds, Wetland Birds, Hummingbirds, Passerine Birds, Seabirds, and Waterfowl. Within each

Table 1. Colloquial avifauna taxonomic groups compiled from all known published records of bird species exposed to the operation of unmanned aircraft systems. (*) Indicates DOI RP survey contributed data to that respective category.

CATEGORY	ORDERS	FAMILIES	SPECIES
BIRDS OF PREY	AccipitDriformes Falconiformes	Accipitridae Cathartidae Pandionidae Falconidae	**7***
FLIGHTLESS BIRDS	Sphenisciformes	Spheniscidae	**7**
WETLAND BIRDS	Ciconiiformes Galliformes Gruiformes	Ciconiidae Phasianidae Gruidae Rallidae	**5***
HUMMINGBIRDS	Apodiformes	Trochilidae	**1***
PASSERINE BIRDS	Passeriformes	Artamidae Corvidae Hirundinidae Meliphagidae Tyrannidae	**10***
SEABIRDS	Charadriiformes Pelecaniformes Phoenicopteriformes Procellariiformes Suliformes	Alcidae Charadriidae Laridae Scolopacidae Ardeidae Pelecanidae Threskiornithidae Phoenicopteridae Diomedeidae Procellariidae Anhingidae Fregatidae Phalacrocoracidae	**42***
WATERFOWL	Anseriformes	Anatidae	**15**
7	**14**	**30**	**87**

group, species typically share a broad geographic range and type of ecosystem they can inhabitant, but resource utilization activities like foraging or nesting sites might be different within the microhabitats present.

While phylogenetic relationships are typically considered the most robust criteria by which to group species phylogenetically speaking, these groupings should allow for more real-world management conclusions to be drawn. This could prove useful for operators working within a particular environment (e.g., coastal areas) who could benefit from knowing which bird species they are likely to encounter (e.g., seabirds) and what distance they will respond to flights. There are also seasonal components to avian biology that would require consideration (i.e., breeding seasons).

Results pertaining to my second and third research questions were also synthesized in tables where I created categories to group the responses or variables reported in the literature. For the second component of my primary research objective to quantify the ethological response of birds to UAS, I compiled and classified behaviors based on whether they produced an antagonistic, neutral, or evasive behavior (Table 2). Antagonistic behaviors included responses often displayed by birds exhibiting territoriality or attacking. Neutral behaviors were primarily natural, undisturbed behaviors typical of a species' that indicate the target species was unaware or at least unalerted by the presence of the UAS operation. Evasive behaviors were reactions such as minor as increased vigilance exhibited by head-cocking or scanning the airspace and as severe as a colony flushing from a site. It is worth noting that in all studies, severe responses from target species would result in researchers retreating or ceasing operations.

To quantify which variables are influential in determining the type and severity of avifauna response, I compiled traits that were identified by researchers and related to either the bird species involved, or the UAS operation and parameters of its flight. One category that I had not explicitly identified at the onset of my project that I later included as its own category was environmental factors (Goebel et al. 2015, Chabot and Bird 2012). Those are shown in Table 3. Wile some of these may be intuitive such as the density of predators in the area or wind impacts on the UAS aircraft

The second project objectives to assess the potential utility of buffer distances, was examined in two ways. For both the data collected from the published literature review, as well as the DOI RP survey, I calculated a mean initial response distance for each avifauna category reported therein. The distance used was again the most conservative reported for a given study (i.e., maximum distance a bird response was detectable) which I called the initial response distance. If a species appeared in multiple independent studies, those were counted individually. However, I did not account for the number of repetitions or pseudo-replicates for each encounter. That is, I was not able to reliably collect how many times a given bird species exhibited a behavior in repeated bouts for a given study. Several studies reported, for example, the number of flights that were conducted in a day. However, in nearly all cases that wasn't enough information to determine how many times an operator's UAV would have been in close proximity and potentially causing disturbance. This effort produced two respective graphs of the average of each of the seven bird categories' initial response distance for each of the species within either the literature review or DOI survey group and comparing them.

Given that mean values can sometimes be misleading or obfuscate informative trends within the data, I also sought to quantify the variance in each of the means. To capture the variability, I constructing a box-and-whisker plot in Microsoft Excel, for the combined dataset incorporating all DOI RP results along with the broader literature review data. The box widths and outlier points illustrate some of the substantial variation that was present in the data collected. Initial response distance was again defined as the most conservative distance at which response behavior was first observed, irrespective of severity. Said another way, this distance is the intervening distance in which researchers observed no effect or behavioral responses, since this is the metric I hoped to quantify.

SECTION 4 – RESULTS

§ 4.1 – Documented Taxonomic Groups

Conducting the review of the literature produced 38 references mentioning at least one bird-UAS interactions or exposure. The majority of these studies (33) were focused on some aspect of bird biology as their central investigation and fell into one of the three categories mentioned in the previous section: habitat, census, or response. The remaining five were either mapping feasibility or review publications. In nearly all cases, the individual study was the first of its kind applying the novel methodology of UAS collected data to a given taxonomic group, or at a particular location, or testing a particular behavioral response (e.g., Mulero-Pazmany et al. 2014, Rodriguez et al. 2012).

In tandem with the data I collected from published literature, I received 20 responses to my questionnaire of the DOI RPs out of 200 that it was distributed to. Each of these consisted of firsthand recounting of UAS-bird interaction observations. The individual record that I myself contributed brought the total responses to 21.

From these collective efforts, I identified 87 individual species that had been observed and recorded as interacting with UAS operations in some proximity (see Table 1). Those species at-large, represented 30 families and 14 orders of birds. In terms of how many species were represented in each of the seven categories I used, seabirds (e.g., gulls, terns, pelicans) were the most numerous group represented with 42 species, followed by waterfowl (e.g., ducks, geese, ibises) with 15 species. The group with the least diversity of species types were the Hummingbirds (1), although as stated earlier this was the author's own contribution in the DOI RP survey. The next group to have minimal number of species were the Wetland birds (e.g., flamingos, storks).

§ 4.2 – Avifauna Ethological Response

At the onset of this project, I had hypothesized that most avifauna would respond to novel UAS operations in their proximity, by retreating in evasive or escape behavior. However, the results of my work to determine how birds will react was more variable an only loosely followed the trend I anticipated. The studies reported and survey reported columns of Table 2 summarize a count of how many of the UAS-avifauna studies

Table 2. Categories and list of specifics behavior observed from published studies and survey results related to Unmanned Aircraft Systems and avifauna interactions.

RESPONSE CATEGORY	BEHAVIOR DESCRIPTION	DATA CAPTURE METHOD	STUDIES REPORTED	SURVEY REPORTED
EVASIVE REACTION –	Fly/swim away Low/high scan Head-cock Off nest Flush Crouch Pause courtship display Break in vocalization	Ground observers Video feed	**19**	**7**
NEUTRAL REACTION 0	Resting Nest maintenance Feather preening	Ground observers	**15**	**5**
ANTAGONISTIC REACTION +	Swooping Mobbing Dive bombing Alarm calling	Ground observers	**11**	**9**

identified evasive reactions within their studies (i.e., if studies contained anecdotes of both evasive and antagonistic ethological response they may be counted twice).

While this is admittedly a coarse way to quantify true ethological response – it does present some interesting patterns among and between groups (studies vs. survey results) that I will discuss further in the Conclusions. The primary highlights in Table 2 come from recognizing the order and frequency with which certain types of behavior examples show up. Currently, within the scientific literature evasive reactions was the most common behavior elicited, but with neutral and antagonistic behaviors of approximately the same magnitude. However, for the survey-reported results the trend did not remain consistent, with antagonistic behaviors being most frequently reported, evasive reactions in the middle, and neutral reactions being the least-often observed. Factors potentially contributing to that trend are discussed in the following section.

§ 4.3 – Variables Affecting Response

The final component of the first half of my research objectives was to determine which variables present in avifauna-UAS interactions could be influencing the resultant ethological response. These are broken down by the component, or source, into characteristics of the UAS, the avifauna, or environmental factors (Rummler et al 2016). Example behaviors describe the types of variables that could be assigned to each of the three components, although some of these are not especially straightforward. For example, wind is an environmental factor but can have a strong influence on the sensory perception of birds, in addition to dramatically being able to alter the flight characteristics of the UAV and increase the noise emitted from the rotors. For the sake of analysis, below I assigned example behaviors to the component they most logically belonged. However, in considering the real-world role of each variable in influencing behavioral response, it is advisable to view them as potentially interrelated or interdependent.

Table 3. Variables of interest by interaction component for the ethological response of avifauna in published literature.

INTERACTION COMPONENT	VARIABLES OF INTEREST	STUDY COUNT
UAS parameters/specs	Configuration (FW vs. VTOL) Silhouette/wing design Angle of approach (overhead down vs. underneath up) Speed of approach Launch distance from target species	19
Avifauna traits	Life stage Reproductive status Age Habituation	15
Environmental conditions	Wind Vegetation density Ambient noise levels Predator abundance/density Magnetic fields	10

§ 4.4 – Distance as a Buffer

Results of my investigation into the utility of establishing setback distance, or buffers, are presented in the following three graphs. When examining them and trying to discern how feasible or effective setting a buffer would be, it is important to keep in mind: (1) variability within and among the seven colloquial categories; (2) limitations set on UAS operators, such as an elevation ceiling imposed on operators by the FAA; and (3) the ability to know before executing a mission which suite of avifauna species may be present within the area. These topics will be revisited in the following sections, but they are useful to have in mind for framing this question within real-world environmental management limitations.

The first two charts (Figure 4A and Figure 4B) are paired given that they both represent the initial response distance reported by either: the collective published literature (Figure 4A) or the reported intervening distances provided by participants in the DOI RP survey (Figure 4B). Both have the categories of avifauna grouped along the x-axis, and the straight-line distance to UAS aircraft in meters along the y-axis. Each category is displaying the mean of all species' most conservative response distance that fell within that category. Each species only contributed a single number per study it appeared in.

I explored the potential to pseudo-replicate events wherein a study reported repeated interactions between a particular bird species and their UAS. However, this proved too arbitrary when trying to apply a consistent formula across different methodologies with varying levels of detail reported within each source. While this restricts my ability to draw conclusions based on properly weighted observations, it allowed for a cleaner analysis in the sense that all observations were somewhat standardized.

In addition to understanding that each species' ethological reaction within a study counted as one value in the meta-analysis, it is important to note that for various reasons, some species used in the totals within Table 1, did not have enough information to determine the initial response distance (Tremblay et al. 2017, Junda et al. 2015, Grenzdorffer 2013). In most cases, this was because the researchers only mentioned an opportunistic interaction that was tangential or unrelated to their primary objective. Therefore, the bird may have come into view too

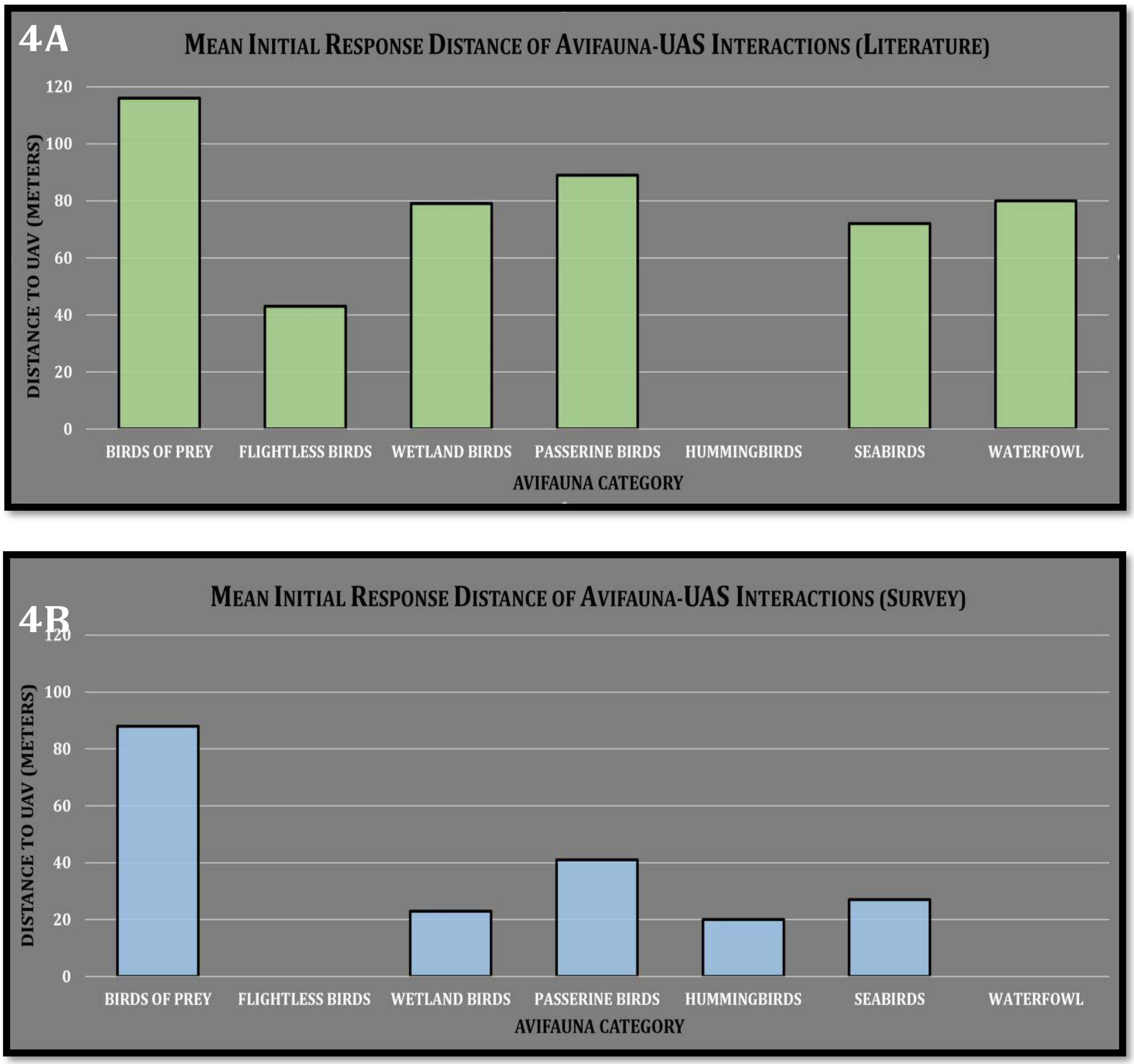

Figure 4. Bar graphs showing the mean initial response distance of avifauna-UAS interactions. Chart 4A shows the mean initial response distance for birds encountering UAS operations, that were reported in the scientific literature. Chart 4B represents the findings from the remote pilot survey distributed to DOI.

quickly to determine at what distance it was initially responding. On the other hand, there were studies designed to test the distance at which a strong or intense reaction was provoked such that researchers did not report the distance when the bird first exhibited a reaction because they initiated making observation notes when they were already in a proximate distance to the bird that it was displaying increased vigilance (Korczak-Abshire et al. 2016).

Several comparisons can be drawn between the two charts. While it is evident the initial response distances are shorter overall in Figure 4B (survey-reported), both generally follow a similar overall trend. Birds of prey had the highest average distance in both plots, which means they exhibited a response from the furthest distance from the UAS operation. Similarly, passerine birds had the next largest average initial response distance in both plots, with wetland and seabirds fairly close to (within 10 meters) of one another after that. Ecological and physiological mechanisms for these patterns are discussed in the following section. It was not possible to make comparisons between the data sources for flightless birds, hummingbirds, or waterfowl, as each of those three categories only appeared from either the literature review or the RP survey.

In addition to taking the average of each bird category, a useful way to analyze the data in terms of robustness is how variable the distribution of each category's individual records. Figure 5 below, is a box-and-whisker plot that captures the range of values in the combined data set. The same categories of bird type are along the x-axis compared to Figure 4, however, the y-axis is a larger scale to show the larger values reported. It appears the avifauna categories with higher mean initial response distances also had the most variable data. There was also substantial variation between groups, with some categories like seabirds and waterfowl having several outlier points identified outside of the upper and lower quartiles. Hummingbirds had functionally no variability, as there was only a single value computed for that category.

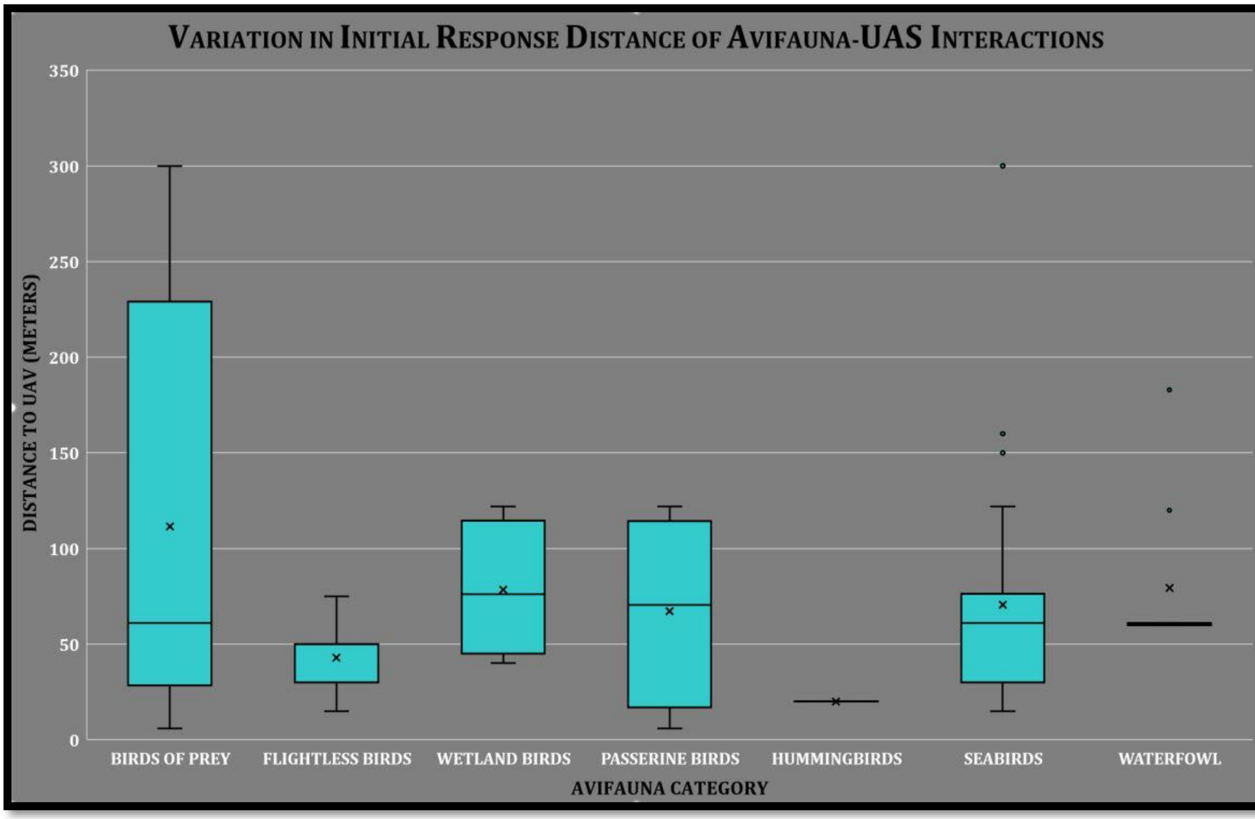

Figure 5. Box and whisker chart showing the distribution of initial response distance for birds encountering UAS operations. This chart represents the combined results of both the literature review as well as the responses to the DOI RP survey used in this analysis.

§ 4.5 – Current Regulatory Environment

To frame this research in the context of environmental management, and to explore the issues legal ambiguity may be imposing on researchers and commercial operators, I searched the online version of the US Library of Congress for pertinent regulations applying to UAS operation around birds. I found five primary statues enacted over the last century that could be applied to the operation of UAS around avifauna species in the wild include: (1) the Endangered Species Act which prohibits the harassment, harm, pursuit, hunting, injury, killing, trapping, capturing, or collecting of any federally-listed endangered or threatened species (in part or whole) which constitutes "take"; (2) the Migratory Bird Treaty Act which similarly prohibits harassment, harm, pursuit, hunting, injury, killing, trapping, capturing, or collecting any migratory bird species, whole or in part; (3) the Bald and Gold Eagle Protection Act which was explicitly enacted to protect these two symbolic and charismatic bird species; and (4) the Airborne Hunting Act (pursuant to Fish and Wildlife Act) which imposes penalties for airborne activities where an aircraft is used to shoot, hunt, harass, etc. that species; and (5) the National Wildlife Refuge System Administration Act of 1966 (pursuant to the Wilderness Act of 1964) which creates designated public areas with protection from human degradation and manipulation, thereby only allowing certain uses consistent with the purpose defined and set forth by Congress (United States Government 1918, 1940, 1956, and 1973).

Three of the five listed in Table 4 are wholly administered by the USFWS. The ESA and general Wilderness Act that the National Wildlife Refuge System Administration Act is pursuant to, are laws having shared authority with NOAA's NMFS, the National Park Service, the US Forest Service, and the Bureau of Land Management. Although there are strict and specific limitations for each statue listed, there exists the possibility that a UAS project could theoretically meet the criteria for an exception, permit, waiver, or similar authorization from the federal agency overseeing the activity. This issue is further discussed in the Conclusions below.

Table 4. Federal United States statutes with provisions applicable to operating UAS near avifauna populations. This study omitted results that could be applied to laboratory settings and research, the shipping or sale of protected species, as well as activities resulting in lethal interactions.

LAW	PROHIBITED ACTIVITIES	APPLIES TO	PERMITS/ WAIVERS?
Migratory Bird Treaty Act	*Intentional*: Harassment Harming/injuring Trapping/capturing	MBTA-protected avifauna (virtually all birds)	Yes; MBTA permit for collecting or monitoring
Endangered Species Act	Harassment Harming/injuring Trapping/capturing	Federally-listed (i.e., endangered, threatened, and proposed) species	Yes; under the of Section 7 or Section 10
Airborne Hunting Act of the Fish & Wildlife Act	Hunting Shooting Harassment	MBTA-protected avifauna (virtually all birds)	Extenuating circumstances
Bald and Gold Eagle Protection Act	Taking Possession Commerce	Bald Eagle Gold Eagle	Extenuating circumstances
National Wildlife Refuge System Administration Act of the Wilderness Act	Any activities inconsistent with intended purpose of wilderness areas	Carrying out wilderness activities	Yes; special use permit

SECTION 5 – CONCLUSIONS

§ 5.1 – Anticipating Behavioral Response

To quantify which types of birds have been exposed to the increasingly popular use of UAS to conduct environmental management and ecological research work, I compiled a comprehensive list of the species, families, and orders of avifauna reported in the literature through early 2018. To that I was able to contribute an additional 13 species that were described within the DOI RP survey I conducted, and not also currently found in the literature. This effort totaled 87 species, which only comprises a small fraction of the total 10,000 – 18,000 estimated species of avifauna globally (Barrowclough et al. 2016). However, in terms of orders, nearly half, 14 of 30, of the known extant avifauna groups were represented in this study (Clements et al. 2016). The studies contained herein also occurred across a diversity of habitats. Therefore, although I cannot draw sweeping conclcusions for all avifaua globally, there are enough studies available to environmental managers to begin thinking critically about designing best management practices and regulations to address the increasing prevalence of bird-drone interactions.

At the start of this project I hypothesized that the majority of bird species encountering UAS would engage in behavior that would allow them to avoid interacting with the operation further. Both the literature review and responses to the DOI RP survey I conducted indicate that is not always the case. The responses from the DOI RP survey are somewhat confounded by the fact that the observers in this case were almost all focused on accomplishing a task unrelated to bird monitoring. However, there were also a substantial amount of published research in which monitoring the activity of nearby avifauna was not eh primary objective of the study. Therefore, any interactions between UAS and avifauna reported, are likely skewed towards antagonistic bird interactions as they are the only type that likely sufficiently pique an operator 's attention. Nevertheless, such a scenario where a UAS operator is focused on the task at hand and must respond to an ensuing encounter with avifauna, is arguably the most representative for what environmental managers should consider when implementing guidance and regulations.

The third component of my research objective to quantify avifauna ethological response to UAS was identifying the factors of influence. Most studies focused on the effects of and identified specific features of the UAS operation (Rodriguez et al. 2012, Ratcliffe et al. 2015) This is not necessarily surprising, given that we have the most control over that aspect of the interaction. Most of the elements I found that were reported as contributing to behavioral response make sense from an avian biology standpoint if we were to consider UAVs analogous to other birds in the sky.

The spatial relationship of birds and UAS was the primary focus of researchers' reports about the influence of modifying flight parameters (Chabot and Bird 2015, Chabot et al. 2015). For example, one study saw marked reactions to the approach of a UAV descending directly overhead of a group of waterfowl – but saw only signs of increased vigilance up to as little as 4 meters when approaching from a low angle in relation to the horizon (Vas et al. 2015). Other studies found that rapid or abrupt approach or overhead changes in direction often caused increased disturbance when compared to slower, regular flight paths (McEvoy et al. 2015). These findings make sense when thinking about aerial predator hunting strategies that prey species of birds have learned and instinctual vigilance responses to.

Additionally, characteristics of the UAS model used was often discussed in this context. UAS models with VTOL configurations were reported as better for ensuring slow and gradual movement like during takeoff and landing, or environmental feature inspections like nesting counts. Researchers used FW UAS models for activities requiring long duration in-air time or for mapping missions requiring large coverage of the surface.

Life history characteristics such as age and reproductive status were the primary traits of avifauna species acknowledged in the majority of studies that described the target species in terms of what may influence behavior. However, several studies were carried out expressly to conduct population census of large, difficult to accurate quantify colonial species. This makes it difficult to assess the role of both reproductive status and level of aggregation in those studies.

A third component of avifauna-UAS interactions that I had previously not given much consideration for was the role of environmental factors in determining interaction outcomes. Wind, density of vegetation, and magnetic fields could all have a significant effect on whether a bird species reacts strongly to the presence of UAS (Hanson et al. 2014, Hughes et al. 2017). No study, however, exclusively tested this but several authors noted their best estimates for the role they had. Another factor that repeatedly arose related to the environment is ambient noise. Sufficiently high ambient noise in the environment can preclude the detection of a drone coming into proximity to a bird species.

§ 5.2 – Using Setback Distance

It was evident that the types of studies examined and the data extracted from various sources varied significantly while compiling my results for this project. Yet, I described the target species in terms of what may influence behavior. However, several studies were carried out expressly to conduct population census of large, difficult to accurate quantify colonial species. This makes it difficult to assess the role of both reproductive status and level of aggregation in those studies.

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Another factor that repeatedly arose related to the environment is ambient noise. Sufficiently high ambient noise in the environment can preclude the detection of a drone coming into proximity was surprised to find that results overall remained fairly consistent when looking at distances at which birds started responding to UAS. This was true between the literature review data and the survey-collected data. It was also true to a certain degree among the types of birds, with most categories having an average initial response distance between 40 and 80 meters regardless of which data collection method it fell within.

Distances reported by the DOI RPs were lower overall than for the research described in publications. This could be due to the fact that often times researchers that were conducting studies explicitly aiming to quantify behavioral response had personnel in place to watch very closely the reactions of birds.

It is important to keep in mind that the metric I used to quantify the response of birds was the largest distance at which the bird initially responds. This is a fairly easy threshold to trigger and is not necessarily equivalent to harassment or even disturbance. The ability to detect changes in behavior, however, is not always easy either. It could be the case that it is both overly conservative to use the first sign of behavioral change as an indication of any real impact to the avifauna in question. Or, it could be that there are more sever impacts occurring to the animal in terms of stress response, that we are not able to easily measure. The physiological response of avifauna to UAS would be a logical next step to this aim.

Results of this work indicate that distance has the potential to be used as an avoidance and disturbance minimization measure for operators of UAS. Examining the graphs from two different data sources shows that if operators were to adhere to the buffer distances I've suggested, they could have a fairly high level of confidence that they operations were not impacting local avifauna. This is partly due to the fact that using initial response distance rather than a distance at which an animal might trigger an escape behavior is already a conservative way to quantity the impact to wildlife. I.e., operators would likely be able to get much closer to bird species if they were approached, before the avifauna species reacted strongly. This is sometimes referred to in the literature as flight initiation distance (Livesky et al. 2016).

§ 5.3 – Ensuring Legal Compliance

The final piece of my investigation was examining the regulatory framework for working in environments with bird species today. Searching the Library of Congress for wildlife laws and regulations indicated the aforementioned laws are somewhat unclear at the time of this writing. Currently, there are not formal mechanisms for permitting commercial operators specifically for operating UAS around birds without assuming the risk for violation of the one of the give statues I identified in the results of this paper (Bickford and Spurrier 2016). At the same time, I was unable to find any case law that detailed any offenses or violations in this realm either.

The lack of established procedures for conducting UAS work around wildlife species, and the birds that share their airspace in particular, was a driving motivation for the subject of my research. I end my treatment of this topic with a summary of best management practices identified from the literature review described next, as well as the results of my investigation into the potential utility of buffer distance for mitigating the impacts to avifauna species. I suspect from personal experience, that the vast majority of UAS pilots hold a desire to operate their equipment without negatively affecting the local species assemblages. I also suspect the regulatory agencies involved with this topic, particularly the USFWS, are likely currently developing guidance regarding the legal ramifications of causing disturbance to species, particularly threatened or endangered species. It is therefore my goal to provide a synthesis herein, of what is known in the commercial and academic spaces, to inform both groups moving forward.

SECTION 6 – RECOMMENDATIONS

Section 6.1 –Management Practices

Several best management practices (BMPs) to reduce the impacts of operating UAS in wildlife habitats have been proposed by researchers in the past (Mulero-Pazmany et al. 2014). These include minimizing noise by choosing electric UAS models over those that are fuel-powered or conducting flights in times of high ambient noise, avoiding the breeding season for sensitive species, and conducting flights using slow, sinuous movements like a lawn-mower pattern rather than directly approaching or descending upon the target species. BMPs specific to avifauna that have been proposed include avoiding UAS of a FW configuration that could resemble aerial predators (i.e., aircraft profile mimicking birds of prey).

In addition to these measures my research on the role of distance suggests that adhering to certain distance thresholds could reduce potential impacts on bird species. As a general rule of thumb, my results indicate that instituting a 100-meter buffer between UAS flights and the nearest bird habitat or individual sightings should preclude the potential for the UAS mission or project to have negative those species. If there are no predatory birds in the area where missions will be conducted, 75 meters is also likely a safe buffer distance to avoid any impacts to avifauna species. If there are birds of prey known to be in the area, or if they are seen overhead foraging, where possible a 125-meter buffer should be in-place to avoid any impacts to avifauna species. While these numbers largely correspond to the mean initial response distance for these categories of birds, most UAS operators will be concerned with avoiding harassment or significant disturbance which could lead to mid-air collisions with their UAS aircraft or could carry legal ramifications if the species is protected.

Developing situational awareness based on the environment one is working in could also help to reduce the possibility for impacts on local avifauna. I propose incorporating an "avifauna checklist" into any site setup guidelines and/or pre-flight standard operating procedures that a corporate entity develops. This should include (A) checking a local bird identification guide or online range mapper to see what species might be present in the area, (B) make note of any high quality habitat for avifauna present when conducting pre-flight reconnaissance via a site walk or aerial imagery assessment and avoiding it where possible, (C) if there are enough personnel on-site, have the individual designed as the pilot-in-command's visual-observer briefed to watch for birds getting near the operation, particularly birds of prey, and (D) have a protocol planned out in advance for the UAS RP to begin initiating that sequence in the event a midair collision seems imminent (either from an aggressive bird swooping and darting, or from causing a colony to flush that is underneath the UAS or in the escape path of the colony). For example, most UAS models have an automatic landing function where the UAS will land as fast as possible directly toward the ground. Some also have a "kill-switch" for really fast airborne complications what when engaged, cuts all power to the UAV and it will simply fall out of the sky. That can carry its own risk, however, and is only advisable in the event of an imminent collision.

Section 6.2 – Regulatory Needs

While NOAA's NMFS has developed guidance and explicit permit application instructions to conduct research or other work over the marine species it protects, I am currently unaware of any analogous steps taken by the USFWS to allow UAS activities. As previously mentioned, instituting and enforcing policies and guidelines to allow the operation of UAS near wild bird species is likely very daunting and complicated. This is especially true when considering the preliminary, varied, and often exploratory nature of the publications and information available to agencies (see below). Basing environmental management decisions and gilding policy based on only preliminary and/or tenuous information, is often an environment inviting litigious interactions in the future. For those reasons among others, it is reasonable to have not seen guidance or permitting channels opened up by USFWS or other federal land management agencies. Nevertheless, in the absence of continued research to develop and test best methodologies for flying near or around birds – the public and private sectors have no opportunity to test these issues.

To address this void I propose that the USFWS and/or other related federal authorities announce in the near-future, a pilot project centered around a mechanism for using UAS in the field and testing the efficacy of different avoidance and minimization measures or best management practices. To kick off such a program, the agency in question could restrict authorized UAS flights to a controlled area where monitoring the response of birds cold be attempted more long-term. This could be done in a variety of settings, and/or the permit application could restrict drone use as the

Section 6.3 – Future Research

As a result of my project's outcomes there are a few key efforts that would greatly improve understanding about this interaction, should they be carried out next. The first would be to design standardized ethological study parameters that researchers could use in the future to collected data which has more utility outside of a single study. Common reporting criteria would allow for more robust reviews and metanalyses. A weakness of the studies on this topic as a whole, suffer from the signs of early observational ecology, wherein is difficult to parse out confounding factors like observer bias that is inherently a risk of ethological methodologies. There also can be a cavalier tendency to extrapolate potentially one-time observations and applying them to a much larger range of possibilities, when we are observing wildlife exhibit new behaviors in response to new stimuli on the landscape.

Secondly, it would be useful to assess the physiological response of birds to UAS. It is possible that the behaviors examined in studies to-date, do not accurately reflect the actual impacts of exposure on birds. An example that illustrates this possibility is a study wherein bears outwardly showed little to no response to UAVs overhead, but sensors on the body of the target animals showed raised levels of stress indictors such as heartbeat (Ditmer et al. 2015). Similar startegies could be used with birds – particularly those engaged in active nesting and incubation. As these are some of environemtnal manager's primary concerns in the long-term effects of disturbance on avifauna, the physiological components of this interaction could be of significatnt value in our understanding of the true interactions at play.

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